IS 4880-6 (1971): Code of practice for design of tunnels conveying water, Part 6: Tunnel support [WRD 14: Water Conductor Systems]

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Indian Standard
CODE OF PRACTICE FOR DESIGN OF TUNNELS CONVEYING WATER
PART VI TUNNEL SUPPORTS

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Indian Standard

CODE OF PRACTICE FOR DESIGN OF TUNNELS CONVEYING WATER

PART VI TUNNEL SUPPORTS

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Indian Standard
CODE OF PRACTICE FOR DESIGN OF TUNNELS CONVEYING WATER
PART VI TUNNEL SUPPORTS

0. FOREWORD

0.1 This Indian Standard (Part VI) was adopted by the Indian Standards Institution on 27 October 1971, after the draft finalized by the Water Conductor Systems Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 Very few tunnels are located in perfectly intact strata throughout their whole length, the vast magnitude being driven through rock with defects of one kind or another requiring some support until the permanent lining can be placed. Even intact rock in areas of high initial stresses may require support to prevent popping. Moreover construction of tunnels involves a large number of problems because of the great longitudinal extent of the work and many kinds of conditions are encountered which for maximum economy should be treated differently. In view of this it has been appreciated that it would be futile to prepare a rigid set of rules or procedures which shall be enforced without leaving any latitude for the exercise of discretion by the site engineer. The aim of this standard is to summarize the well-known and proved principles and to describe the commonly used procedures and techniques for providing guidelines which would permit the site engineer to use his discretion.

0.3 In view of the inherent advantages of the steel supports over timber supports, the use of the former is recommended and only steel supports are covered in this standard. In olden days timber was used in tunnel supports but now steel has become almost universally adopted as the standard material for supporting tunnels. Sometimes, however, timber may have to be used for tunnel supports.

0.3.1 Steel supports have the following advantages over timber supports:

a) Steel ribs are easier to handle and require much less storage space;

b) Steel ribs when compared to timber would be smaller, section wise and as such overall cross-sectional area of excavation will be less;

c) Steel ribs become a part of permanent lining and also act as reinforcement. Thus, the thickness of lining will be less;

d) Steel ribs do not deteriorate like timber;

e) Steel ribs can be fabricated to the required shape before hand in the shop and, therefore, their erection is faster; and

f) No specially skilled personnel are required for erection of steel supports.

0.4 This standard is being published in parts. Other parts are as follows:

Part I	General design
Part II	Geometric design
Part III	Hydraulic design
Part IV	Structural design of concrete lining in rock
Part V	Structural design of concrete lining in soft strata and soils

0.5 This standard is one of a series of Indian Standards on tunnels.

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This standard (Part VI) covers the criteria for design of steel supports and roof bolts for tunnels and shafts in rock and soft strata.

NOTE — This standard should be used in conjunction with IS : 5878 (Part IV)-1971†.

2. TERMINOLOGY

2.1 For the purpose of this standard, the definitions given in IS : 5878 (Part IV)-1971† shall apply.

3. MATERIALS

3.1 Structural steel sections for tunnel supports shall confrom to IS : 808-1964‡ and IS : 226-1962§.

3.2 Concrete shall generally conform to IS : 456-1964||.

4. GENERAL

4.1 Before taking up the design of supports, the rock load and pressures likely to act on the supports shall be estimated. The determination of rock

*Rules for rounding off numerical values (*revised*).
†Code of practice for construction of tunnels : Part IV Tunnel supports.
‡Specification for rolled steel beam, channel and angle sections (*revised*).
§Specification for structural steel (standard quality) (*fourth revision*).
||Code of practice for plain and reinforced concrete (*second revision*).

load is a complex problem. This complexity is due to inherent difficulty of predicting the primary stress conditions in the rock mass (prior to excavation) and also due to the fact that the magnitude of the secondary pressure developing after the excavation of the cavity depends on a large number of variables, such as size and shape of cavity, depth of cover, disposition of strike and dip of rock formation in relation to alignment of tunnel, method of excavation, period of time elapsing before rock is supported and the rigidity of supports. These pressures may not develop immediately after excavation but may take a long period after excavation to develop due to adjustment of displacements in the rock mass.

4.1.1 In major tunnels it is recommended that as excavation proceeds, load cell measurements and diametral change measurements are carried out so that rock loads may be correctly estimated. In rocks where the loads and deformation do not attain stable values, it is recommended that pressure measurements should be made by using flat jack or pressure cells.

4.2 In the absence of any data and investigations, rock loads may be estimated in accordance with Appendix B of IS : 4880 (Part V)-1971*.

4.3 As the tunnels generally pass through different types of rock formations, it may be necessary to workout alternative cross-sections of the tunnel depicting other acceptable types of support systems. These types may be selected to match the various methods of attack that may have to be employed to get through the various kinds of rock formations likely to be encountered. 'A' and 'B' lines shall be shown on these sections.

4.4 The support system shall be strong enough to carry the ultimate loads. For a reinforced concrete lining it is economical to consider the supports as an integral part of the permanent lining.

5. TYPES OF STEEL SUPPORT SYSTEM

5.1 Rock tunnel support system of steel may be generally classified into the following principal types:

a) Continuous rib;
b) Rib and post;
c) Rib and wall plate;
d) Rib, wall plate and post; and
e) Full circle rib.

NOTE — Invert strut may be used in addition with types (a) to (d) where mild side pressures are encountered [*see also* IS : 5878 (Part IV)-1971†].

6. SELECTION OF TYPE OF SYSTEM

6.1 For selection of type of support system, a reference may be made to IS : 5878 (Part IV)-1971†.

*Code of practice for design of tunnels conveying water : Part V Structural design of concrete lining in soft strata and soils.

†Code of practice for construction of tunnels : Part IV Tunnel supports.

7. COMPONENTS OF TUNNEL SUPPORT

7.1 For constituents of support system a reference may be made to IS : 5878 (Part IV)-1971*.

8. FACTORS DETERMINING SPACING AND LAYOUT OF SUPPORTS

8.1 The strength and spacing of rib system shall be determined by rock load. For a given rock load and cross-section of tunnel the spacing between the ribs and whether the ribs shall be in two or more pieces shall be worked out. The spacing of the ribs should be so chosen that the sum of the cost of ribs and lagging is minimum. For preliminary designs in ordinary rocks the depth or rib section may be taken as 60 to 75 mm for every 3 metre of bore diameter with ribs spaced at about 1·2 m for moderate loads, 0·6 to 1·0 m for heavy loads and 1·6 m for very light loads.

8.2 For junctions, plugs and control chamber, etc, supports shall be designed to suit the special features of the work and its construction procedures.

8.3 Wooden or concrete blocks of suitable size and thickness may be provided, if necessary, in the bottom portion to provide adequate bearing area to the rib.

8.4 In tunnels, where supports are not to be used as reinforcement, they may be installed plumb or perpendicular to the axis of the tunnel depending on tunnel slope and as found convenient. However, where supports are to be used as reinforcement in pressure tunnels, they may be installed at right angles to the tunnel axis, if practicable.

8.5 For speed of erection of supports it is essential to:

a) design the support system with the minimum number of individual members, consistent with construction convenience;

b) design the joints with utmost simplicity and absolute minimum number of bolts; and

c) fabricate the members with sample bolt and wrench clearances. Time consuming close fits shall be avoided.

9. DESIGN

9.1 General — The design of steel components for tunnel supports shall generally conform to IS : 800-1962†.

9.2 Stresses — Permissible stresses in steel shall be in accordance with IS : 800-1962†. However, if the ribs are bent cold, the maximum permissible fibre stress in steel shall be 1 990 kg/cm².

*Code of practice for construction of tunnels : Part IV Tunnel supports.

†Code of practice for use of structural steel in general building construction (*revised*).

9.3 Ribs — Rock load may be assumed to be transmitted to the ribs at blocking points; each blocking point carrying the load of the mass of rock bounded by four planes, namely, the longitudinal planes passing through mid-points between the blocks and transverse planes passing through mid-points between the ribs to a height equal to the acting rock load. The blocking points may be assumed to be held in equilibrium by forces acting on it in the same manner as panel points in a truss. Values of thrust in the rib may be computed by drawing the force polygon. Ribs shall be designed for the thrust thus computed taking into account the eccentricity of this thrust with reference to the rise of the arc between the blocking points which will cause flexural stresses in addition to direct stresses.

9.4 Tie Rods — *See* IS : 5878 (Part IV)-1971*.

9.5 Lagging — Lagging may be designed for the load of rock mass as shown in Fig. 1 [*see also* IS : 5878 (Part IV)-1971*].

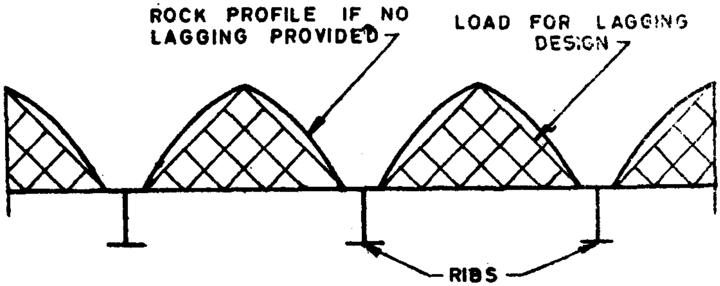


FIG. 1 LOADING DIAGRAM FOR LAGGING

9.6 Liner Plates — Where only liner plates are used for support their cross-sectional area and their joints shall be designed to transmit the thrust (*see* **9.3**). It shall be ensured that liner plates are thoroughly in contact with ground so that passive resistance is developed and no bending moments are induced. For tunnels with more than 3 m diameter liner plates may be reinforced by I-beams. Where liner plates do not form a ring and are used in top half with ribs they shall be designed as lagging [*see also* IS : 5878 (Part IV)-1971*].

9.6.1 The thickness of liner plates may vary from 3 to 10 mm depending upon the size of bore and loads encountered. The size of bolts may vary from 12 to 16 mm diameter.

9.7 Joints — Butt joints should be preferred to spliced joints. In soft grounds and poor rock, welding of joints in the field should be avoided as far as possible.

*Code of practice for construction of tunnels : Part IV Tunnel supports.

10. ROOF BOLTS

10.1 General — Roof bolting follows the principle of fastening the loose rocks near the surface to the solid rock above by means of anchor bolts instead of supporting it from below. Roof bolts not only support the surface rock but also assist it to act as a load carrying element.

10.2 Types — For the types of roof bolts which may be used, a reference may be made to IS : 5878 (Part IV)-1971*.

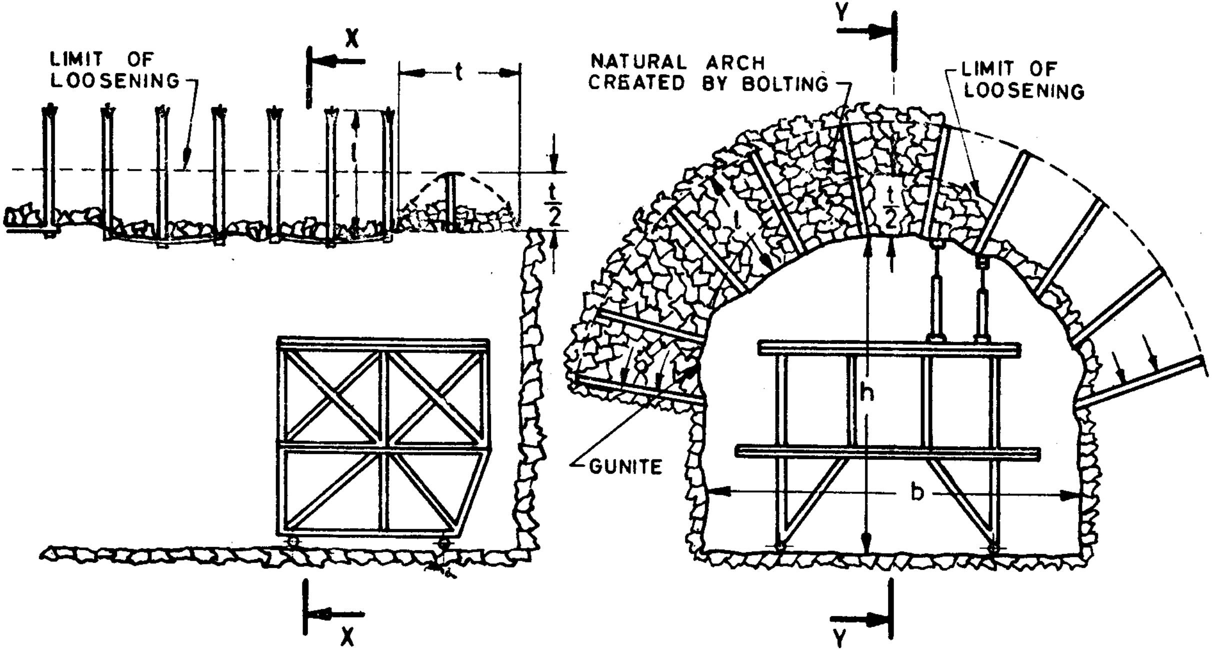
10.3 Design — Immediately after a tunnel has been advanced by a length t (*see* Fig. 2), the rock in this section expands and settles slightly developing a double arch effect. In the longitudinal direction of the tunnel, the arch rests on the still untouched rock at the front and on the already supported portion at the back (*see* arrows in Fig. 2). The second arch effect, perpendicular to the axis of the tunnel is given by the form of the roof, which usually is an arch in tunnels. The period to which this combined arch will stand without support depends on the geological conditions, the length t and the radius of the tunnel roof, but in most cases, even in badly disintegrated rock, it will be possible to maintain this natural arch for some time, at least a couple of hours. If the natural arch is not supported immediately after mucking, it will continue to sink down slowly until it disintgerates.

10.3.1 The portion that is liable to fall is generally parabolic in cross-section having a depth $t/2$ though the loosening process will never go as deep as this if the movement is stopped by quick support. Nevertheless, it is recommended that the bolts should not be made shorter than t that is twice the depth of the presumed maximum loosening. The natural surrounding rock of the cavity is in this way transformed into a protective arch, the thickness of which is given by the length of the bolts l which should be bigger ~~than~~ t; also $l > \frac{b}{4}$ to $\frac{b}{3}$, as the arch also should have a certain relation to the width of tunnel.

10.3.2 The rock requires a prestress by bolting and the bolts should follow the static principles of prestressing in reinforced concrete as much as possible. As it is not possible to place bolts in the way of stress bars at the lower side of a beam, they should at least be given an oblique position in order to take the place of bent-up bars and stirrups (*see* Fig. 3).

10.3.2.1 With an arch instead of a beam, the shear forces will be greatly reduced by the vault effect but even in arch shaped roofs, shear forces may be caused by joint systems, especially by system of parallel layers like sedimentary formations, scists, etc. Hence the bolts should not only be made to exert a strong prestress to the rock but also should be set in a direction which

*Code of practice for construction of tunnels : Part IV Tunnel supports.



SECTION YY

SECTION XX

FIG. 2 DIAGRAMMATIC SECTIONS DEMONSTRATING PRINCIPLES OF ROOI BOLTING suits best to the static demands of the geological conditions as shown in Fig. 3.

10.3.2.2 Just as a static member of reinforced concrete has to be prestressed before receiving the load, the rock also shall be prestressed by bolting before the load develops. This means that the space '*t*' in Fig. 2 shall be bolted immediately after blasting and at the same time as the next round is being drilled.

10.3.3 The space between the bolts shall be chosen in accordance with the length and diameter of the bolts. Assuming for instance that a bolt is given a load of 12 tonnes taking into consideration a sufficient factor of safety, this would correspond to a rock volume of 4·5 m^3 at a density of 2·65 t/m^3. If the length of the bolt allows a thickness of the protective arch of 2·5 m each bolt will correspondingly carry an area of the load of:

$$\frac{12}{2{\cdot}65 \times 2{\cdot}5} = 1{\cdot}8 \text{ m}^2$$

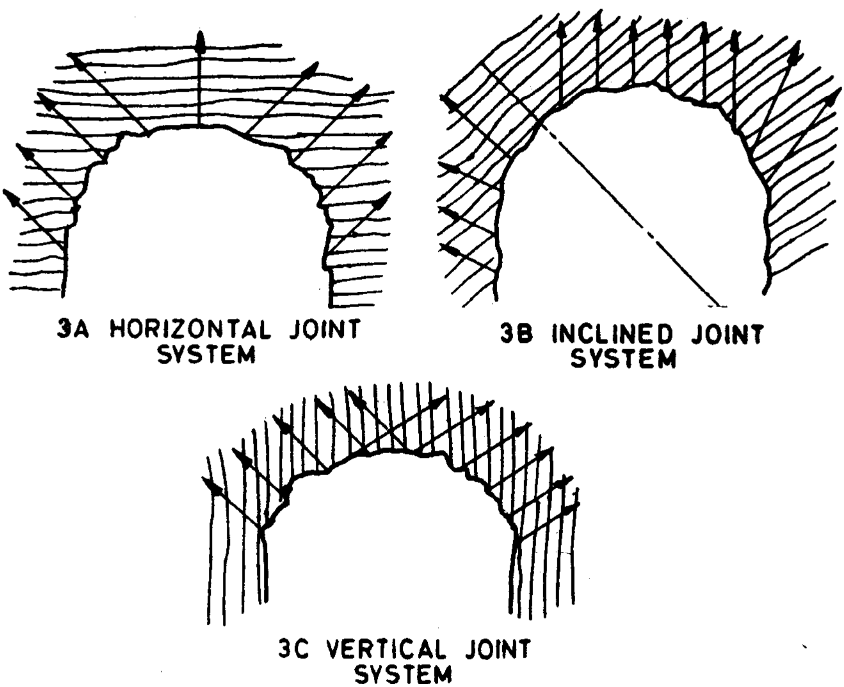


FIG. 3 ROOF BOLTING IN STRATA RUNNING AT VARIOUS ANGLES OF DIP

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